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APPROXIMATE METHOD OF CALCULATING AERODYNAMIC WING CHARACTERIST--ETC(U)
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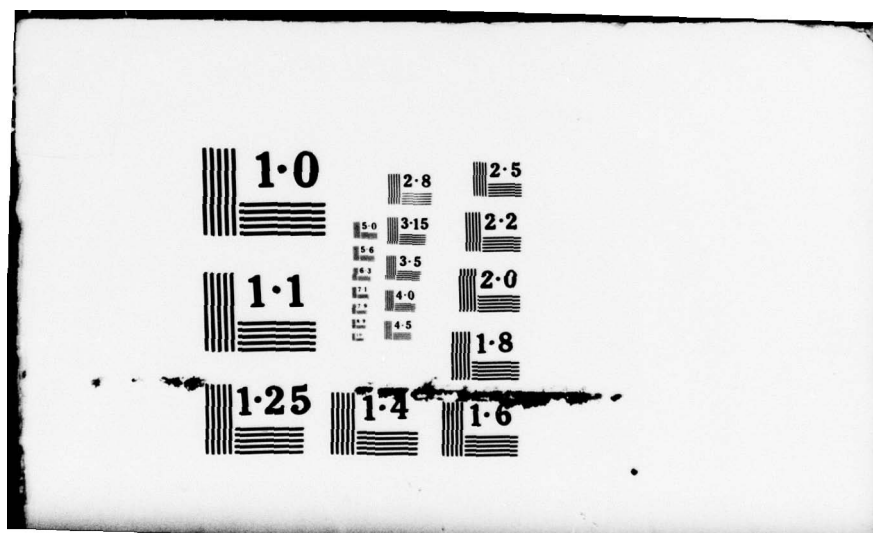
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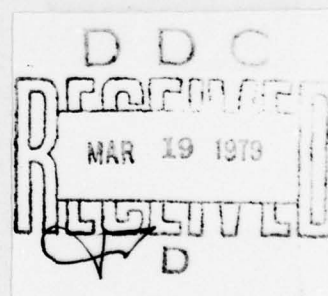
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APPROXIMATE METHOD OF CALCULATING AERODYNAMIC
WING CHARACTERISTICS IN THE PRESENCE OF
A CYLINDRICAL BODY

by

V. A. Grayvoronskiy



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А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З э	<i>З э</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

*ye initially, after vowels, and after Ъ, ь; e elsewhere.
 When written as ё in Russian, transliterate as yë or ë.
 The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	A α α	Nu	N ν
Beta	B β	Xi	Ξ ξ
Gamma	Γ γ	Omicron	Ο ο
Delta	Δ δ	Pi	Π π
Epsilon	Ε ε ε	Rho	Ρ ρ ϱ
Zeta	Ζ ζ	Sigma	Σ σ ς
Eta	Η η	Tau	Τ τ
Theta	Θ θ ϑ	Upsilon	Υ υ
Iota	Ι ι	Phi	Φ φ ϕ
Kappa	Κ κ κ	Chi	Χ χ
Lambda	Λ λ	Psi	Ψ ψ
Mu	Μ μ	Omega	Ω ω

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
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sin	sin
-----	-----

cos	cos
-----	-----

tg	tan
----	-----

ctg	cot
-----	-----

sec	sec
-----	-----

cosec	csc
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sh	sinh
----	------

ch	cosh
----	------

th	tanh
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cth	coth
-----	------

sch	sech
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csch	csch
------	------

arc sin	\sin^{-1}
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arc cos	\cos^{-1}
---------	-------------

arc tg	\tan^{-1}
--------	-------------

arc ctg	\cot^{-1}
---------	-------------

arc sec	\sec^{-1}
---------	-------------

arc cosec	\csc^{-1}
-----------	-------------

arc sh	\sinh^{-1}
--------	--------------

arc ch	\cosh^{-1}
--------	--------------

arc th	\tanh^{-1}
--------	--------------

arc cth	\coth^{-1}
---------	--------------

arc sch	sech^{-1}
---------	----------------------------

arc csch	csch^{-1}
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rot	curl
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lg	log
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1636

APPROXIMATE METHOD OF CALCULATING AERODYNAMIC WING CHARACTERISTICS IN
THE PRESENCE OF A CYLINDRICAL BODY

V. A. Grayvoronskiy

The continuous flow of a steady perfect incompressible fluid about the combination of a wing with a small aspect ratio and a cylindrical body is considered in the nonlinear formulation.

The wing is considered to be thin, slightly curved, and its surface is near the plane of the meridian.

In order to solve the problem, wing cantilevers are simulated by a system of oblique horseshoe vortices. It is assumed that the bound lifting vortices are arranged like those of an isolated wing [1]. The

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free vortices converge with the wing surface [2]. The cylindrical body is replaced by a flat dipole and a system of vortices which are the reflection of the wing vortex system. The free vortices of the wing are assumed to be stepped with sufficiently small spacing t (Fig. 1) when constructing the reflected vortex system. The position of the reflected points of the vortex system is determined from the formula

$$r^* = \frac{a^2}{r}, \quad (1)$$

where r^* and r are the distances from the axis of the cylinder to the reflected point and the point being reflected, respectively; a is the radius of the cylinder. Here the value and direction of the sections parallel to the axis of the cylinder do not change during reflection, while the sections perpendicular to the axis of the cylinder are transformed into peripheral arcs.

We will introduce the dimensionless coordinates

$$\xi = \frac{x_1}{\delta}; \quad \eta = \frac{y_1}{\delta}; \quad \zeta = \frac{z_1}{\delta},$$

where

$$\delta = \frac{L}{4n}(1 - \sigma);$$

L is the wingspan; n is the number of elements into which the

cantilever is broken down in the direction of the span;

$$\sigma = \frac{2a}{L}.$$

Using ν to designate the horseshoe vortex in the direction of axis α_ν ($1 \leq \nu \leq n$) and μ - in the direction of axis α_μ ($1 \leq \mu \leq m$), we will have the following geometric relationships for the vortex system.

The angle of sweep of the reflected bound vortex -

$$\chi_{\nu\mu}^* = -\arctg \left(\frac{\operatorname{tg} \chi_\mu}{\delta_\nu^*} \right), \quad (2)$$

where $\delta_\nu^* = \frac{a^2}{2} \left(\frac{\zeta_\nu - \zeta_{\nu-1}}{\zeta_\nu \cdot \zeta_{\nu-1}} \right)$

is the half-span of the reflected horseshoe vortex.

The coordinates of the breaking points of the reflected free vortices are determined by the formulae:

$$\begin{aligned}
 \xi_{\nu\mu}(s) &= \xi_{\nu\mu}(0); \\
 \eta_{\nu\mu}(s) &= \frac{a^2 s \operatorname{tg} \gamma_{\nu\mu}}{(s \operatorname{tg} \gamma_{\nu\mu})^2 + (a + 2v)^2}; \\
 \zeta_{\nu\mu}(s) &= \frac{a^2 (a + 2v)}{(s \operatorname{tg} \gamma_{\nu\mu})^2 + (a + 2v)^2};
 \end{aligned}
 \tag{3}$$

Here s is the sequence number of the stage of an arbitrary stepped vortex ($s = 0, 1, 2, \dots, N$); $\gamma_{\nu\mu}$ is the angle of inclination of the free vortex, which is far away from the axis of the cylinder. The angle of inclination of the free vortex, which converges with element $v=1$ and is close to the cylinder's axis, is assumed to be equal to zero.

The boundary conditions of the impenetrability of the wing at points j, q are:

$$1 + \frac{a^2}{(a + 2j - 1)^2} + (V_{\nu\mu}^s)_{jq} = 0 \quad (1 \leq j \leq n, 1 \leq q \leq m), \tag{4}$$

where

$$(V_{\nu\mu}^s)_{jq} = \frac{(V_{\nu\mu}^s)_{jq}}{V_\infty \sin \alpha};$$

$(V_{\nu\mu}^s)_{jq}$ is the velocity from the vortex system in the direction of axis Ox . The angles of inclination of the free vortices to plane $\xi O \xi$

are determined by the direction of the local velocity at point F, whose projection on plane $\xi o \zeta$ is a certain distance Δb from the trailing edge of the cantilever cross section (Fig. 1). Here the formula for determining the direction of a free vortex with numbers i, p is

$$\operatorname{tg} \gamma_{ip} = \frac{1 + a^2 \frac{\zeta_i^2 - \eta_{ip}^2}{(\zeta_i^2 + \eta_{ip}^2)^2} + (V_{\zeta i}^*)_{ip}}{\operatorname{ctg} a + (V_{\xi i}^*)_{ip}} \quad (1 \leq i \leq n, 1 \leq p \leq m), \quad (5)$$

where $(V_{\xi i}^*)_{ip}, (V_{\eta i}^*)_{ip}$ is the velocity at point $(\xi_{ip}, \eta_{ip}, \zeta_i)$ from the vortex systems.

The velocity operator in direction k can be written as:

$$\begin{aligned} (V_{\xi k}^*)_0 = & \sum_{j=1}^n \sum_{\mu=1}^m \left\{ \Gamma_{\nu\mu}^* [(V_k)_0^{\nu\mu} + (W_k)_0^{\nu\mu} + (V_{r,k}^*)_0^{\nu\mu} + (V_{s,k}^*)_0^{\nu\mu} + (W_k)_0^{\nu\mu}] \right\}_{\nu=1}^3 + \\ & + \sum_{\nu=2}^n \Gamma_{\nu\mu}^* [(V_k)_0^{\nu\mu} - (V_k)_0^{\nu-1\mu} + (W_k)_0^{\nu\mu} + (V_{r,k}^*)_0^{\nu\mu} + (V_{s,k}^*)_0^{\nu\mu} - (V_{r,k}^*)_0^{\nu-1\mu} - \\ & - (V_{s,k}^*)_0^{\nu-1\mu} + (W_k)_0^{\nu\mu}], \end{aligned} \quad (6)$$

where $\Gamma_{\nu\mu}^* = \frac{\Gamma_{\nu\mu}}{4\pi\delta V_\infty \sin\alpha}$; $\Gamma_{\nu\mu}$ is the intensity of the ν, μ -th vortex;

$(V_k)_0^{\nu\mu}, (W_k)_0^{\nu\mu}$ are the velocities from the corresponding free and bound vortices of identical intensity; $(V_{r,k}^*)_0^{\nu\mu}, (V_{s,k}^*)_0^{\nu\mu}, (W_k)_0^{\nu\mu}$ is the velocity from the reflected horizontal, vertical, and bound vortex segments, respectively.

Coefficient f determines the cantilever. In view of the insignificant effect of values $(V_{\alpha\alpha})_0^{(n)}$ on the solution, they can be disregarded.

Equations (4) and (5) are solved by the method of successive approximations. The numerical calculations showed that the nature of the convergence of the solution due to the iteration process corresponds to the case of an isolated wing [2]. The effect of values $\Delta b, t$ on the solution is insignificant.

Using N. Ye. Zhukovskiy's theorem on lift "on a small scale," after simple transformations we will obtain the following for coefficients c_n and c_m in the j -th cross section:

$$(c_n)_j = \frac{2\pi\lambda_h \left(\frac{1}{\gamma_h} + 1 \right) \sin^2 \alpha}{n - \left(1 - \frac{1}{\gamma_h} \right) (2j-1)} \sum_{p=1}^m \Gamma_p^* [\operatorname{ctg} \alpha + (V_{\alpha\alpha})_{jp} - (V_{\alpha\alpha})_{jp} \operatorname{tg} \chi_p]; \quad (7)$$

$$(c_m)_j = - \frac{2\pi\lambda_h \left(\frac{1}{\gamma_h} + 1 \right) \sin^2 \alpha}{m \left[2n - \left(1 - \frac{1}{\gamma_h} \right) (2j-1) \right]} \sum_{p=1}^m \Gamma_p^* [\operatorname{ctg} \alpha + (V_{\alpha\alpha})_{jp} - (V_{\alpha\alpha})_{jp} \operatorname{tg} \chi_p] \quad (p = 0, 75). \quad (8)$$

For the wing on the whole

$$c_n = \frac{2\pi\lambda_k \sin^2 \alpha}{n^2} \sum_{j=1}^n \sum_{p=1}^m \Gamma_{jp}^* [\operatorname{ctg} \alpha + (V_{\xi\xi}^a)_{jp} - (V_{\xi\xi}^a)_{jp} \operatorname{tg} \chi_p]; \quad (9)$$

$$m_z = - \frac{2\pi\lambda_k \sin^2 \alpha}{n^2} \sum_{j=1}^n \sum_{p=1}^m \Gamma_{jp}^* [\operatorname{ctg} \alpha + (V_{\xi\xi}^a)_{jp} - (V_{\xi\xi}^a)_{jp} \operatorname{tg} \chi_p] \times \\ \times \left(\frac{p-0.75}{m} + \frac{2j-1}{b_1} \operatorname{tg} \chi_p \right), \quad (10)$$

where λ_k is the aspect ratio of the cantilever; b_1 is the root chord; $\eta_k = \frac{b_1}{b_{\text{кону}}}$ ($b_{\text{кону}}$ is the tip chord of the cantilever).

The numerical calculations made by computer agree satisfactorily with the experimental data. Figure 2 shows the distribution of the coefficient of normal force over the span - $\bar{z} = 2 \frac{-a}{L-2a}$ for a straight wing ($\lambda_k = 2.00$, $\sigma = 0.185$) which is centrally located on the cylindrical body. Figure 3 shows a graph of the dependence $c_y = f(\alpha)$ of the combination of a wing and a cylindrical body ($\lambda_k = 0.61$, $\sigma = 0.39$, $\lambda_{k,r} = 10$). The lift coefficient was determined from the formula

$$c_y = c_{y_k}(k_k + \Delta k_k) + c_{y_{k,r}} \frac{S_k}{S_r}, \quad (11)$$

c_{y_k} is the lift coefficient of isolated wing cantilevers; k_k , Δk_k are the coefficients which consider the effect of the cylindrical body on the cantilever, and vice versa, respectively; $c_{y_{k,r}}$ is the

lift coefficient of the isolated body; S_m, S_k are the areas of the middle of the cylindrical body and the wing cantilever; $c_{y,k}$ is the lift coefficient of the cantilever in the presence of the cylindrical body, determined by this method. Δk was determined by the theory of thin bodies.

The lift coefficient of an isolated housing was calculated from the Allen formula [3]:

$$c_{y,HT} = 2\alpha + c_{xu} \frac{S_{n,HT}}{S_M} \sin^2 \alpha, \quad (12)$$

c_{xu} was assumed to be equal to 0.35, which agreed with the experimental data for an isolated housing; $S_{n,HT}$ is the area of the housing in the plane.

Figure 4 shows the characteristic distribution of the normal velocities in the cross section of the cylinder calculated for a vortex system with one free vortex ($\Gamma^* \sin \alpha = 1; \sigma = 0.5$) at $\gamma = 15^\circ$ and $\gamma = 0^\circ$.

The value $(V_{u1})_{\rho}$ was disregarded in the theoretical calculations.

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3. H. R. Kelly. Estimation of Normal-Force, Drag, and Pitching-Moment Coefficients for Blunt-Based Solids of Revolution at Large Angles of Attack, IAS, VIII, August 1954, V. 21.

Fig. 1.

KEY: (1) Arbitrary stepped vortex.

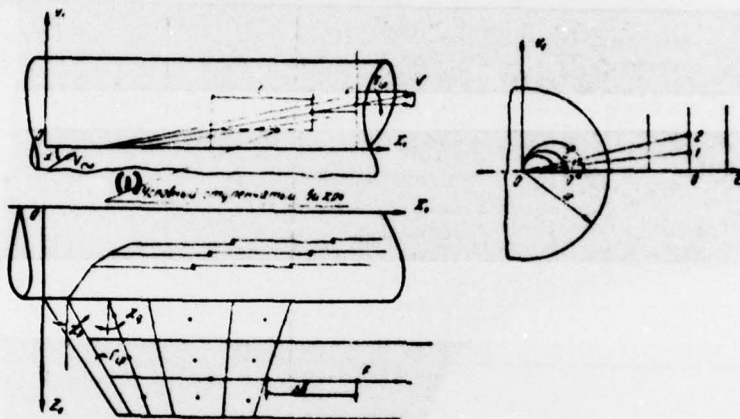


Fig. 2.

KEY: (1) Nonlinear method. (2) Linear method. (3) Experiment.

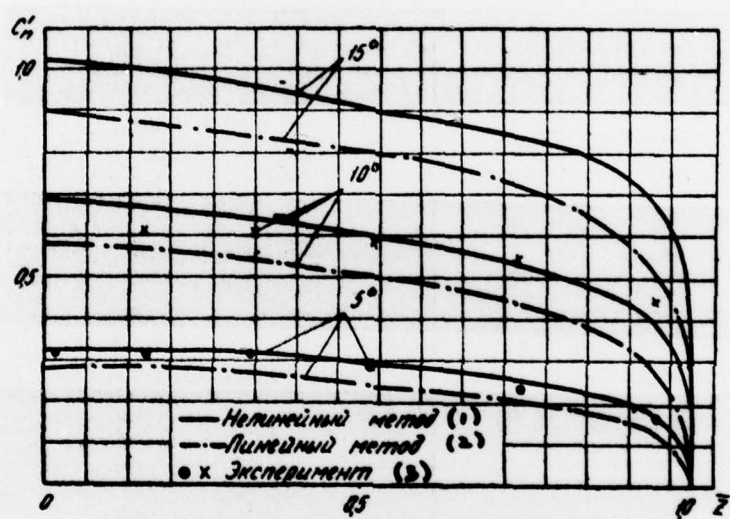


Fig. 3.

KEY: (1) Nonlinear method. (2) Linear method. (3) Experiment.

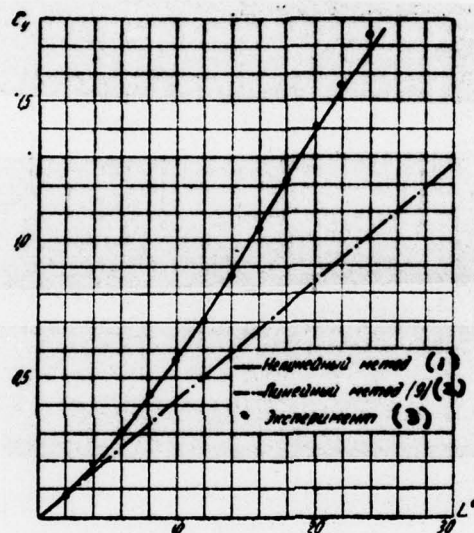
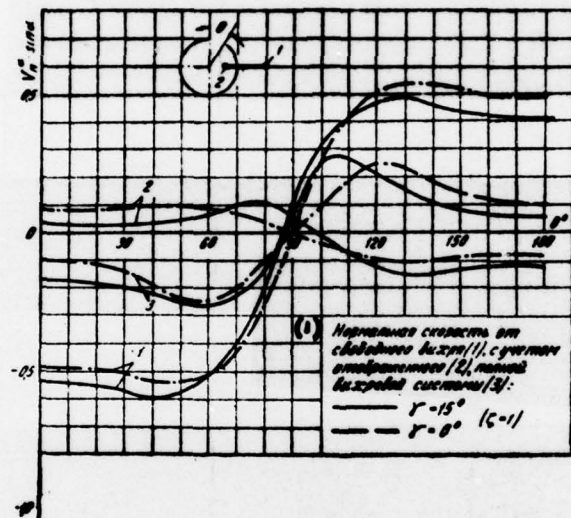


Fig. 4.

KEY: (1) Normal velocity from free vortex (1), with consideration of reflected (2), complete vortex system (3).



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